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Comparison of diets containing various fish meal levels on growth performance, body composition, and insulin-like growth factor-I of juvenile channel catfish *Ictalurus punctatus* of different strains

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Abstract

A 3×3 factorial experiment was conducted in flow-through aquaria to evaluate effects of diets, containing 0%, 4%, or 8% menhaden fish meal, on growth performance, body composition, and insulin-like growth factor-I (IGF-I) of juvenile channel catfish of Mississippi "normal" (MN), NWAC103 [formally known as USDA103], or USDA303 strains. Twenty fish with an average weight of 4.7±0.1 g fish^{-1} (±S.D.) were stocked into each of 36, 110-l aquaria (four aquaria per treatment). Fish were fed 28%-protein diets containing various levels of fish meal to approximate satiation twice daily for 9 weeks. Regardless of fish strain, fish fed diets containing 4% or 8% fish meal had higher diet consumption, final weight, and feed efficiency (FE) than fish fed an all-vegetable diet. Regardless of fish meal level, NWAC103 and USDA303 channel catfish consumed more diet, gained more weight, and converted diet more efficiently than MN fish. No differences were observed in diet consumption, final weight, and FE between NWAC103 and USDA303 strains. There was an interaction in specific growth rate between fish strain and fish meal level. Specific growth rate was greater for MN fish fed diets containing 4% or 8% fish meal than fish fed the all-vegetable diet, whereas there were no differences in specific growth rate for NWAC103 and USDA303 fish fed various diets. Fillet protein was lower and fillet fat was higher for NWAC103 and USDA303 strains than for the MN strain. Plasma IGF-I levels were greater in NWAC103 and USDA303 channel catfish than in MN fish. Levels of IGF-I were similar between NWAC103 and USDA303 fish. The addition of fish meal to the all-vegetable diet for the three strains did not affect levels of IGF-I. Mean plasma IGF-I concentration was positively correlated to specific growth rate. Results from the present study indicated that the optimum inclusion level for fish meal was 4% of a soybean meal-based diet (fish meal levels higher than 8% were not evaluated in the present study). Including 4% fish meal in the diet improved the performance more for the MN strain than for NWAC103 and USDA303 strains, suggesting that a genotype-diet interaction exists in juvenile channel catfish. Performance of the NWAC103 and USDA303 channel catfish fed the all-vegetable diet was better than MN fish fed the same diet. Plasma IGF-I concentration may be a good indicator for channel catfish growth.

Keywords: Channel catfish; Strain; Fish meal; Growth; Insulin-like growth factor-I

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1. Introduction

Fish meals produced from whole fish are excellent sources of protein for fish feeds because of their high protein quality and palatability. However, because fish meal is of limited supply and more expensive than most other protein sources, reducing its use while maintaining optimum fish performance will increase profits and maintain sustainability of the aquaculture industry. Several studies have been conducted to evaluate effects of replacing fish meal with plant protein sources on channel catfish growth with mixed results (Andrews and Page, 1974; Mohsen and Lovell, 1990; Webster et al., 1992; Robinson and Li, 1994; Reigh, 1999; Li et al., 2003). Different results from various studies may be caused by variations in diet composition, feed allowance, fish size and strain, and environmental conditions. Various strains of fish may have different nutrient requirements or respond to diet composition differently, indicating a genotype-nutrition interaction. Such interaction has been demonstrated in Nile tilapia (Romana-Eguia and Doyle, 1992). However, the interaction between genotype and nutrition appears to be insignificant for rainbow trout (Smith et al., 1988). Li et al. (1998, 2001) and Jackson et al. (2003) evaluated effects of dietary protein concentration on various channel catfish strains under laboratory and pond conditions and found that different strains of channel catfish (USDA102, NWAC103 [formally known as USDA103], Mississippi "normal", and Norris strains) have a similar dietary protein requirement. Little is known of responses of different channel catfish strains to various diet compositions.

The growth hormone (GH)/insulin-like growth factor-I (IGF-I) (GH–IGF-I) network plays an integral role in mammalian growth (Jones and Clemmons, 1995). In mammals, IGF-I is a major regulator of growth and the concentration found in the plasma is regulated by a complex interaction between receptors and binding proteins (Baxter, 1994). Mounting evidence suggests that IGF-I plays a similar role in the growth of fish (Duan, 1997, 1998; Moriyama et al., 2000). Perez-Sanchez and Le Bail (1999) first proposed that the GH–IGF-I network could be used as a marker of growth performance and nutritional status in cultured fish. Recently, Dyer et al. (2004) demonstrated that IGF-I levels increased with increasing ration size in barramundi, and IGF-I was positively correlated to growth rates obtained in Atlantic salmon. The results of that study suggested that measuring levels of IGF-I might provide a useful tool for monitoring fish growth rate as well as a method to assess different diet formulations. However, there is lack of information on IGF-I levels in channel catfish in relation to growth rate as influenced by fish strain and diet composition. The purpose of the present study was to evaluate effects of diets containing various levels of fish meal (0%, 4%, or 8%) on diet consumption, growth, feed efficiency (FE), body composition, and IGF-I levels of different channel catfish strains (MN, NWAC103, or USDA303).

2. Materials and methods

Three 28%-protein, practical diets (Table 1) were formulated to contain 0%, 4%, or 8% menhaden fish meal with digestible energy/protein (DE/P) ratio ranging from 42.0 to 43.3 kJ g^{-1} of protein. The DE/P ratio was allowed to vary to follow practices in commercial feed formulations. All known nutrient requirements of channel catfish were satisfied (NRC, 1993). The diets were prepared as sinking pellets according to procedures described previously (Li et al., 1993). The diets were stored at −30 °C until used. The menhaden fish meal (regular grade) was obtained from Omega Protein, Inc. (Hammond, LA, USA). Other feed ingredients were

Table 1
Ingredient and proximate composition of experimental diets (percentage, as-fed)

Ingredient	Fish meal (%)		
	0	4	8
Soybean meal [a] (48%)	39.90	34.22	28.55
Cottonseed meal (41%)	5.00	5.00	5.0
Menhaden fish meal (61%)	0.00	4.00	8.0
Corn grain (extrusion-cooked)	40.09	42.23	44.37
Wheat middlings	10.00	10.00	10.00
Dicalcium phosphate	1.25	0.76	0.32
C-free vitamin mix [b]	0.10	0.10	0.10
Vitamin C [c]	0.06	0.06	0.06
Trace mineral mix b	0.10	0.10	0.10
Carboxymethylcellulose	2.00	2.00	2.00
Catfish offal oil	1.50	1.50	1.50
DE/P ratio [d]	42.0	42.7	43.3
Proximate composition [e] (n=2)			
Crude protein	28.13±0.21	28.58±0.14	28.36±0.03
Crude fat	3.26±004	3.42±0.01	3.90±0.03
Ash	5.26±0.07	5.76±0.02	5.81±0.07

[a] Numbers in parentheses represent percentage crude protein.
[b] Same as described by Robinson et al. (2001).
[c] Provided by L-ascorbyl-2-polyphosphate (25% activity).
[d] DE/P ratio = digestible energy to crude protein ratio. The DE was estimated based on tabular values of NRC (1993) and Robinson et al. (2001) (kJ g^{-1}).
[e] Values represent the mean±S.D.

obtained from the Delta Western Feed Mill (Indianola, MS, USA) and were from commercial sources.

Forty juvenile channel catfish (*Ictalurus punctatus*) from three strains (MN, NWAC103, and USDA303) were stocked into each of 36, 110-l flow-through, glass aquaria at the National Warmwater Aquaculture Center (NWAC), Mississippi State University, Stoneville, MS, USA. The MN strain representing a commercial stock currently cultured in Mississippi, USA was obtained from a local commercial catfish farm. The NWAC103 strain (described by Wolters et al., 2000) was developed through selective breeding at the U.S. Department of Agriculture (USDA) Catfish Genetics Research Unit, Stoneville, MS, for two generations before its release in 2001. This strain has been further selected for rapid growth for an additional two generations to produce the USDA303 strain. The NWAC103 and USDA303 fingerlings were obtained from the USDA Catfish Genetics Research Unit, Stoneville, MS. The channel catfish of mixed families from all strains were obtained from pond spawns within a 1-week period.

The aquaria were supplied with well water (flow rate = approximately 1 l min^{-1}) and continuous aeration. Water temperature was maintained at 30 ± 1 °C. A photoperiod of 14:10-h L/D was used. Before initiation of the experiment, the fish were conditioned for 2 weeks and fed a 28%-protein diet containing 4% fish meal twice daily to satiation at 0800 and 1600 h. After conditioning, all fish were pooled and graded into a uniform size, and 20 fish were restocked in each aquarium. Initial fish weight was determined and averaged 4.7 ± 0.1 g $fish^{-1}$ (±S.D.). Initial weights were similar among the fish strains. Fish were fed to apparent satiation twice daily for 9 weeks. Dead fish, if any, were removed daily from the aquarium and weighed. Aquaria were cleaned weekly.

Fish in each aquarium were counted and groups were weighed every 3 weeks. At the end of feeding period, diet consumption and final weight per fish, specific growth rate (SGR), FE, and survival were determined. Specific growth rate and FE were determined as follows:

$$\text{SGR, \% per day} = (\text{Ln}[\text{final fish weight, g fish}^{-1}] - \text{Ln}[\text{initial fish weight, g fish}^{-1}]) / (\text{number of days fish were fed}) \times 100.$$

$$\text{FE} = ([\text{final fish weight, g tank}^{-1}] - [\text{initial fish weight, g tank}^{-1}] + [\text{weight gain of mortality, g tank}^{-1}]) / (\text{total diet fed, g tank}^{-1}).$$

After determining the final fish number and weight, five fish from each aquarium were euthanized by an overdose of tricaine methanesulfonate (MS-222, Argent Chemical Laboratories, Redmond, WA, USA). Fish muscle tissue (fillet) samples were removed, pooled by aquarium, and stored at −30 °C for subsequent proximate analyses. The fillet samples were homogenized into a paste by means of a food processor. Part of the sample was lyophilized with Freezone Freeze Dry System (Labconco, Kansas City, MO, USA) for 16 to 18 h for protein and fat analyses. Proximate analyses were conducted in duplicate on the composite samples with methods described by AOAC (2000). Crude protein of fillet samples was analyzed by combustion method with the FP-2000 protein determinator (Leco Corporation, St. Joseph, MO, USA), crude fat by ether extraction with the Soxtec System (Foss North America, Inc., Eden Prairie, MN, USA), moisture by oven drying with a mechanical convection oven (Precision, Winchester, VA, USA), and ash with a muffle furnace (Type 30400, Barnstead Thermolyne Corporation, Dubuque, IA, USA).

At the end of the study, four fish from each aquarium were euthanized with an overdose of MS-222 and bled from the caudal vasculature with heparinized syringes for plasma IGF-I analysis. Plasma was separated from whole blood by centrifugation. Plasma IGF-I levels were measured with a competitive time-resolved fluoroimmunoassay validated for channel catfish (Small and Peterson, 2005). Sensitivity of the assay was 0.20 ng ml^{-1} and intra- and inter-assay coefficients of variance were <7% and <12%. Serial dilutions of plasma were parallel to the standard curve and recovery of IGF-I from spiked plasma samples was >90%. Plasma samples were acid-ethanol-extracted prior to assaying and standards were run in triplicate, whereas samples were run in duplicate.

Data were subjected to two-way analysis of variance and the Fisher's protected least-significant-difference procedure (Steel et al., 1997) with the Statistical Analysis System (SAS) version 9.1 software (SAS Institute, Inc., Cary, NC, USA). Simple correlation between plasma IGF-I and SGR was also conducted with SAS. Aquaria were the experimental units and variation among aquaria within a treatment was used as the experimental error in tests of significance. A significant level of $P \leq 0.05$ was used.

3. Results

At the end of weeks 3, 6, and 9, the NWAC103 and USDA303 channel catfish gained more weight than the MN fish, whereas there was no difference in body

weight between the NWAC103 and USDA303 fish (Fig. 1). At the end of weeks 6 and 9, the fish fed diets containing 4% and 8% fish meal gained more weight than fish fed an all-vegetable diet, whereas there was no difference in body weight between fish fed diets containing 4% and 8% fish meal (Fig. 2).

At end of the 9-week feeding period, diet consumption, final weight, SGR, and FE were affected by both fish strain and fish meal level (Table 2). Survival ranged from 98.8% to 100% and was not influenced by either fish strain ($P=0.067$) or fish meal level ($P>0.10$). Regardless of fish strains, fish fed diets containing 4% or 8% fish meal had greater diet consumption, final weight, and FE than fish fed the all-vegetable diet. Regardless of fish meal levels, the NWAC103 and USDA303 channel catfish consumed more diet, gained more weight, and converted diet more efficiently than the MN fish. There were no differences in diet consumption, final weight, or FE between the NWAC103 and USDA303 strains. No interactions were observed between fish strain and fish meal level for diet consumption, final weight, FE, or survival. However, there was an interaction in SGR between fish strain and fish meal level. Specific growth rate was greater for the MN fish fed diets containing 4% or 8% fish meal than fish fed the all-vegetable diet, whereas there were no differences in SGR for the NWAC103 and USDA303 fish fed various diets.

Plasma IGF-I levels were greater in the NWAC103 and USDA303 channel catfish than in the MN fish (Table 2). Levels of IGF-I were similar between the NWAC103 and USDA303 channel catfish. The addition of fish meal to the diet for the three strains did not affect IGF-I levels. There was no interaction for IGF-I between fish strain and fish meal level. Mean plasma IGF-I concentration was positively correlated to SGR ($r^2=0.70$, Fig. 3).

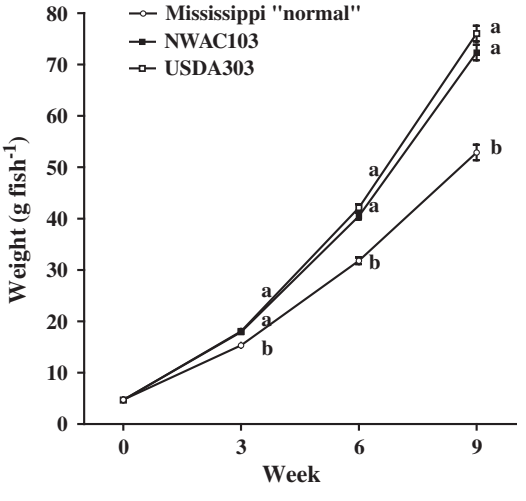

Fig. 1. Growth curve of juvenile channel catfish of Mississippi "normal", NWAC103, and USDA303 strains. Each datum point represents a pooled mean of each strain fed various diets. Means followed by different letters were different ($P\leq 0.05$).

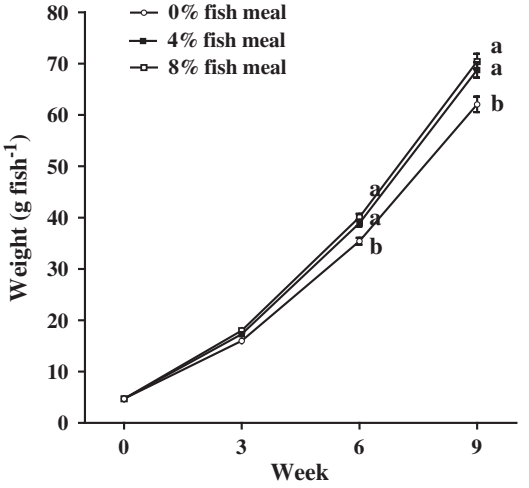

Fig. 2. Growth curve of juvenile channel catfish fed diets containing 0%, 4%, or 8% fish meal. Each datum point represents a pooled mean of each fish meal level fed to various fish strains. Means followed by different letters were different ($P\leq 0.05$).

Fillet protein, fat, and ash concentrations were influenced by fish strain, but not by fish meal level (Table 3). Fillet moisture level was not affected by either fish strain or fish meal level. Fillet protein was lower and fillet fat was higher for the NWAC103 and USDA303 strains than for the MN strain. The NWAC103 strain had lower fillet ash than the MN strain. There were no interactions in fillet composition between fish strain and fish meal level.

4. Discussion

Results from the present study indicated that, regardless of fish strain, diet consumption, final weight, and FE improved when the juvenile channel catfish were fed a diet containing 4% menhaden fish meal, compared with the fish fed an all-vegetable diet. No further improvement was noted when fish meal level increased to 8% of the diet. In a previous study (Li et al., 2003), we did not observe significant differences ($P>0.10$) in diet consumption, weight gain, or FE among juvenile channel catfish fed diets containing 0%, 6%, or 12% menhaden fish meal (weight gain was 49.0, 48.7, and 52.1 g fish^{-1} and FE was 0.881, 0.893, 0.935 for fish fed diets containing 0%, 6%, or 12% fish meal,

Table 2
Mean diet consumption, final weight, feed efficiency, survival, and insulin-like growth factor-I (IGF-I) of different strains of channel catfish fed practical diets containing various levels of fish meal in flow-through aquaria for 9 weeks

Fish strain	Fish meal level (%)	Diet consumption [a] (g fish^{-1})	Final weight [b] (g fish^{-1})	Specific growth rate (% day^{-1})	Feed efficiency [a] (gain/feed)	Survival (%)	IGF-I (ng ml^{-1})
Individual treatment means							
MN [c]	0	66.0	44.7	3.38 e	0.606	98.8	3.9
MN	4	74.9	56.3	3.78 d	0.686	98.8	5.4
MN	8	76.6	57.7	3.83 d	0.691	98.8	7.0
NWAC [d]	0	82.1	69.0	4.14 c	0.784	100.0	8.2
NWAC103	4	84.7	71.5	4.20 bc	0.788	100.0	8.0
NWAC103	8	89.4	76.5	4.32 bc	0.801	100.0	8.0
USDA [e]303	0	83.3	72.5	4.23 bc	0.813	100.0	6.4
USDA303	4	89.0	78.5	4.37 ab	0.828	100.0	7.5
USDA303	8	89.1	77.1	4.34 b	0.811	100.0	8.1
Pooled S.E.		1.84	2.61	0.062	0.0165	0.72	0.40
Means of main effects [f]							
MN		72.5 v	52.9 v	–	0.661 v	98.8	5.4 v
NWAC103		85.4 u	72.3 u	–	0.791 u	100.0	8.1 u
USDA303		87.1 u	76.0 u	–	0.817	100.0	7.3 u
	0	77.1 y	62.1 y	–	0.734 y	99.6	6.1
	4	82.9 x	68.8 x	–	0.768 x	99.6	6.9
	8	85.0 x	70.4 x	–	0.768 x	99.6	7.9
Analysis of variance: P-values							
Fish strain		<0.001	<0.001	<0.001	<0.001	0.067	0.026
Fish meal		<0.001	<0.001	<0.001	0.027	1.00	0.22
Fish strain × Fish meal		0.40	0.33	0.036	0.069	1.00	0.62

[a] Diet consumption was on dry matter basis.
[b] Mean initial weight was 4.7±0.1 g fish^{-1} (±S.D., n=36) for the three strains of channel catfish. There were no significant differences in initial fish weight among treatments (P-values for fish strain, fish meal, and fish meal × fish meal were 0.34, 0.99, and 0.99, respectively).
[c] Mississippi "normal" strain.
[d] National Warmwater Aquaculture Center.
[e] U.S. Department of Agriculture.
[f] Within a column, means of main effects followed by different letters are different ($P \leq 0.05$, the Fisher's protected least-significant-difference procedure). Means of main effects for specific growth rate were not reported because of a significant interaction between fish strain and fish meal level.

respectively). However, improvements in weight gain and FE have been reported for juvenile channel catfish raised in aquaria and fed diets containing menhaden fish meal levels up to 20% (Mohsen and Lovell, 1990) and 30% (Andrews and Page, 1974). Although growth and FE improvements achieved by supplementing high levels of fish meal in the diet in those studies might partially be related to the high energy or fat content contributed by fish meal, improvements by the addition of low levels of fish meal might not be explained by the slight increase in energy or fat concentrations. Mohsen and Lovell (1990) found that channel catfish fed diets containing 5–10% fish meal had significantly greater weight gain and FE than fish fed a basal diet without fish meal and that supplementing catfish oil to the basal diet did not improve fish performance. In the present study, differences in final weight, SGR, and FE in the fish fed diets with and without fish meal were unlikely caused by differences in dietary essential amino acid compositions because all diets were formulated to meet or exceed amino acid requirements of channel catfish. Adding synthetic lysine and methionine to a soybean meal-based, all-vegetable diet has been shown to be ineffective in improving channel catfish growth (Andrews and Page, 1974). The increase in growth and FE in juvenile channel catfish fed the levels of fish meal used in the present study appeared to be due to improved palatability of the diet as suggested by Mohsen and Lovell (1990).

Specific growth rate was affected by fish strain, fish meal level, and their interaction in the present study. For the MN fish, SGR was greater for fish fed diets containing 4% and 8% fish meal than fish fed the all-vegetable diet, whereas there were no differences in SGR for the NWAC103 and USDA303 fish fed diets containing 0%, 4%, or 8% fish meal. The interaction between fish strain and fish meal level suggests that

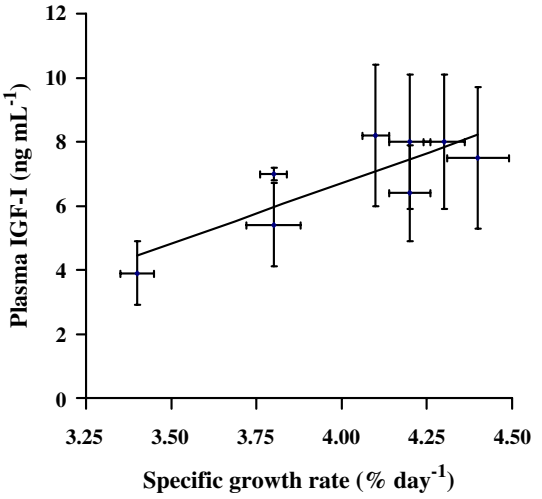

Fig. 3. Relation of insulin-like growth factor-I (IGF-I) concentration and specific growth rate (SGR) of three strains of channel catfish. The three strains of catfish demonstrated a strong correlation ($y=-8.365+3.776x$; $r^2=0.70$; $P\leq 0.05$) between IGF-I concentration and SGR at the end of the 9-week study. Values are mean±S.E. Vertical error bars refer to the *y*-axis and horizontal error bars to the *x*-axis.

different channel catfish strains respond differently to diet compositions associated with fish meal levels. The NWAC103 and USDA303 strains appeared to have greater tolerance to the all-vegetable diet (lower-cost diet) than the MN strain. Since the NWAC103 strain (USDA303 strain was originated from the NWAC103 strain) consumes more feed than other strains (Li et al., 1998, 2001; Silverstein et al., 1999; Jackson et al., 2003), it may be less sensitive to diet palatability than other strains.

Although there were no significant interactions between fish strain and fish meal level in the present study, the addition of fish meal to the diet appeared to improve the diet consumption, final weight, and FE more for the MN strain than for the NWAC103 and USDA303 strains. On average, adding 4–8% fish meal to the all-vegetable diet increased final weight of the MN strain by 27.5%, while there was only 7.2–7.3% increase in final weight for the NWAC103 and USDA303 strains. Similar trends were also noted for diet consumption. There was a 13.6% increase in FE of the MN strain, whereas FE was essentially the same for the NWAC103 and USDA303 strains, when 4–8% fish meal was included in the diet. In a previous study with NWAC103 channel catfish (mean weight was 6.6 g $fish^{-1}$) cultured under similar conditions as used in the present study, weight gain and FE were not significantly different among fish fed diets containing 0%, 6%, or 12% fish meal (Li et al., 2003). In contrast, Mohsen and Lovell (1990) observed a 57% increase in weight gain and 9% improvement in FE of channel catfish (an unknown strain) when a soybean meal-based diet was supplemented with 5–10% fish meal. There appears to be a genotype–diet interaction in channel catfish. This interaction was also observed for Nile tilapia. Romana-Eguia and Doyle (1992) found that certain strains of Nile tilapia grew faster than other strains when fed different diets. However, Smith et al. (1988) compared growth of 10 rainbow trout strains fed diets formulated with either plant or animal proteins and found that differences in growth rate were caused by fish strains but not by dietary protein sources or by the dietary protein × strain interaction.

In the present study, the NWAC103 and USDA303 strains consumed 17.8% and 20.1% more diet, had 36.7% and 43.7% higher final weight and 19.7% and 23.6% higher FE than the MN strain. The growth data

Table 3
Mean protein, fat, moisture, and ash concentrations (wet-tissue basis) in fillets of different strains of channel catfish fed practical diets containing various levels of fish meal in flow-through aquaria for 9 weeks

Fish strain	Fish meal level (%)	Fillet protein (%)	Fillet fat (%)	Fillet moisture (%)	Fillet ash (%)
Individual treatment means					
MN[a]	0	18.3	4.36	76.3	1.25
MN	4	18.2	4.25	76.5	1.23
MN	8	18.0	4.74	76.1	1.23
NWAC[b]103	0	17.6	5.20	76.1	1.22
NWAC103	4	17.8	5.20	76.0	1.24
NWAC103	8	17.6	5.49	75.9	1.22
USDA[c]303	0	17.6	5.13	76.1	1.21
USDA303	8	18.0	5.16	75.7	1.21
Pooled SE		0.16	0.282	0.26	0.010
Means of main effects[d]					
MN		18.2 u	4.45	76.3	1.24 u
NWAC103		17.7 u	5.30 u	76.0	1.21v
USDA303		17.8 v	5.15 u	75.9	1.23 uv
	0	17.8	4.90	76.2	1.23
	4	17.9	4.87	76.2	1.23
	8	17.9	5.13	75.9	1.22
Analysis of variance: P-values					
Fish strain		0.001	0.002	0.18	0.025
Fish meal		0.87	0.48	0.42	0.47
Fish strain × Fish meal		0.30	0.93	0.93	0.52

[a] Mississippi "normal" strain.
[b] National Warmwater Aquaculture Center.
[c] U.S. Department of Agriculture.
[d] Within a column, means of main effects followed by different letters are different (P≤0.05, the Fisher's protected least-significant-difference procedure).

agreed with our previous reports (Li et al., 1998, 2001) that demonstrated that the NWAC103 strain grew faster than the MN strain when raised in either aquaria or earthen ponds. Other studies also show that the NWAC103 strain exhibits superior growth characteristics compared with other channel catfish strains that have been evaluated (Wolters et al., 2000; Jackson et al., 2003). The faster growth of the NWAC103 strain is primarily due to higher feed intake of the fish, as was seen in the present study and in previous studies (Li et al., 1998, 2001; Silverstein et al., 1999; Jackson et al., 2003). Moreover, improved FE was also observed in the NWAC103 and USDA303 strains compared with the MN strain in the present study. Li et al. (1998) also reported that the NWAC103 strain converted diet more efficiently than the MN strain raised in aquaria.

The USDA303 strain was obtained by further selection of the NWAC103 strain for two more generations for faster growth. Unpublished data indicated that there was about 21% improvement in growth of the USDA303 strain over the NWAC103 strain (Small, in press). In the present study, there were no significant differences in diet consumption, final weight, or FE between the NWAC103 and USDA303 strains at the 0.05 probability level. However, there appeared to be marginal improvements in final weight (5.1%, $P=0.092$) and feeding efficiency (3.3%, $P=0.06$) for the USDA303 strain over the NWAC103 strain.

Previous studies indicate that the NWAC103 strain contains more fat in the fillet than the MN strain (Li et al., 1998, 2001). Data from the present study also showed that the NWAC103 and USDA303 strains had higher fat levels in the fillet than the MN strain. It should be noted that the NWAC103 and USDA303 strains were larger in size than the MN strain. It is not clear whether the difference in fish size significantly affected the apparent differences in fillet fat levels among different strains. The present study also showed that the NWAC103 and USDA303 strains contained a similar level of moisture, but a lower level of protein in the fillet than the MN strain. These results disagree with our previous reports (Li et al., 1998, 2001) which showed that the NWAC103 strain contained a higher level of moisture, but a similar level of protein compared with the MN strain. The cause for the difference in fillet moisture and protein levels among these studies is not clear. However, fast-growing fish (manipulated through feed allowance) are generally high in body fat and low in moisture and protein concentrations compared with slow-growing fish at the same body weight (Robinson et al., 2003).

It is well documented that IGF-I is one of the key factors in controlling growth in most mammalian species. Silverstein et al. (2000) and Peterson et al. (2004, 2005) have suggested that IGF-I is an important hormone involved in growth of channel catfish. To the best of our knowledge, this is the first study to demonstrate a direct correlation between plasma IGF-I concentration and SGR in channel catfish. These results are in agreement with Dyer et al. (2004) who showed that IGF-I was positively correlated to growth rates in barramundi and Atlantic salmon. Results of the present study and the study of Dyer et al. (2004) suggest that circulating plasma levels of IGF-I are a useful tool to predict growth rates of cultured fish. Furthermore, if IGF-I could be used as a marker of growth performance and as a predictor of future performance of fish, it could significantly impact fish selective breeding programs. Although there was a positive correlation between levels of IGF-I and SGR, the NWAC103 and USDA303 strains were larger in size than the MN strain. It is not clear what effect fish size has on levels of plasma IGF-I. The correlation between IGF-I and SGR observed in the present study might be a result of the NWAC103 and USDA303 fish being larger at the end of the study. Future studies will need to discern the difference between fish size and concentrations of plasma IGF-I.

5. Conclusion

Results from the present study indicated that a diet containing 4% menhaden fish meal provided optimum growth and FE of juvenile channel catfish raised in flow-through aquaria (fish meal levels higher than 8% were not evaluated in the present study). Including 4% fish meal in the all-vegetable diet improved fish performance more for the MN strain than for the NWAC103 and USDA303 strains, suggesting that a genotype–diet interaction exists in juvenile channel catfish. Performance of the NWAC103 and USDA303 strains fed the all-vegetable diet was better than the MN strain fed the same diet. Plasma IGF-I levels may be a good indicator of growth rate of channel catfish.

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